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(54) **METHOD AND SYSTEM FOR CHARGE DETERMINATION**

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F24F 11/36 (2018.01)
F25B 40/02 (2006.01)

(52) **U.S. Cl.**

CPC ***F25B 49/005*** (2013.01); ***F24F 11/36*** (2018.01); ***F25B 45/00*** (2013.01); *F25B 40/02* (2013.01); *F25B 2345/003* (2013.01); *F25B 2500/222* (2013.01); *F25B 2700/21162* (2013.01); *F25B 2700/21163* (2013.01)

(58) **Field of Classification Search**

CPC F25B 39/04; F25B 40/02; F25B 45/00; F25B 2345/003; F25B 2700/21163

See application file for complete search history.

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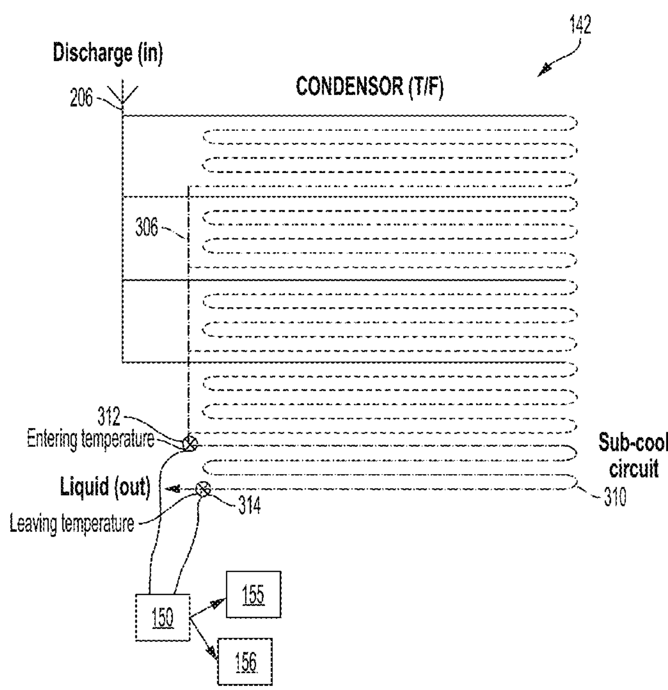
(57) **ABSTRACT**

An HVAC system includes an evaporator coil and a compressor fluidly coupled to the evaporator coil. A condenser coil is fluidly coupled to the compressor. The condenser coil includes at least one condenser circuit fluidly coupled between a discharge line and an exit manifold. A sub-cool circuit is fluidly coupled between the exit manifold and a liquid line. A first temperature sensor is disposed at an entrance to the sub-cool circuit. A second temperature sensor is disposed at an exit to the sub-cool circuit. An HVAC controller is operatively coupled to the first temperature sensor and the second temperature sensor. The HVAC controller is configured to determine a temperature difference across the sub-cool circuit.

20 Claims, 10 Drawing Sheets



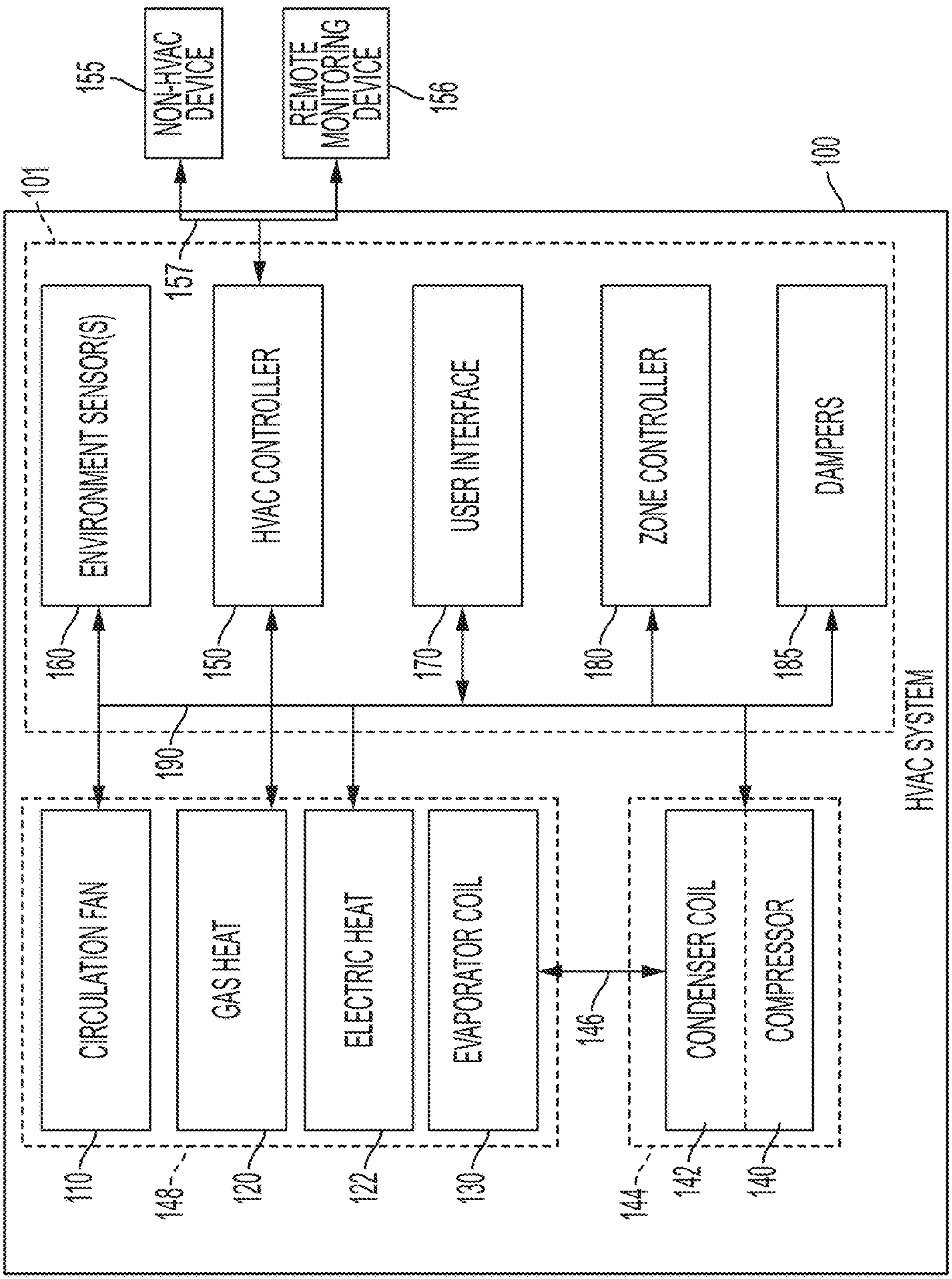

NON-HVAC DEVICE
155
REMOTE MONITORING DEVICE
156
100
101
157
ENVIRONMENT SENSOR(S)
HVAC CONTROLLER
USER INTERFACE
ZONE CONTROLLER
DAMPERS
160
150
170
180
185
190
HVAC SYSTEM
CIRCULATION FAN
GAS HEAT
ELECTRIC HEAT
EVAPORATOR COIL
CONDENSER COIL
COMPRESSOR
146
110
148
120
122
130
144
142
140

FIG. 1

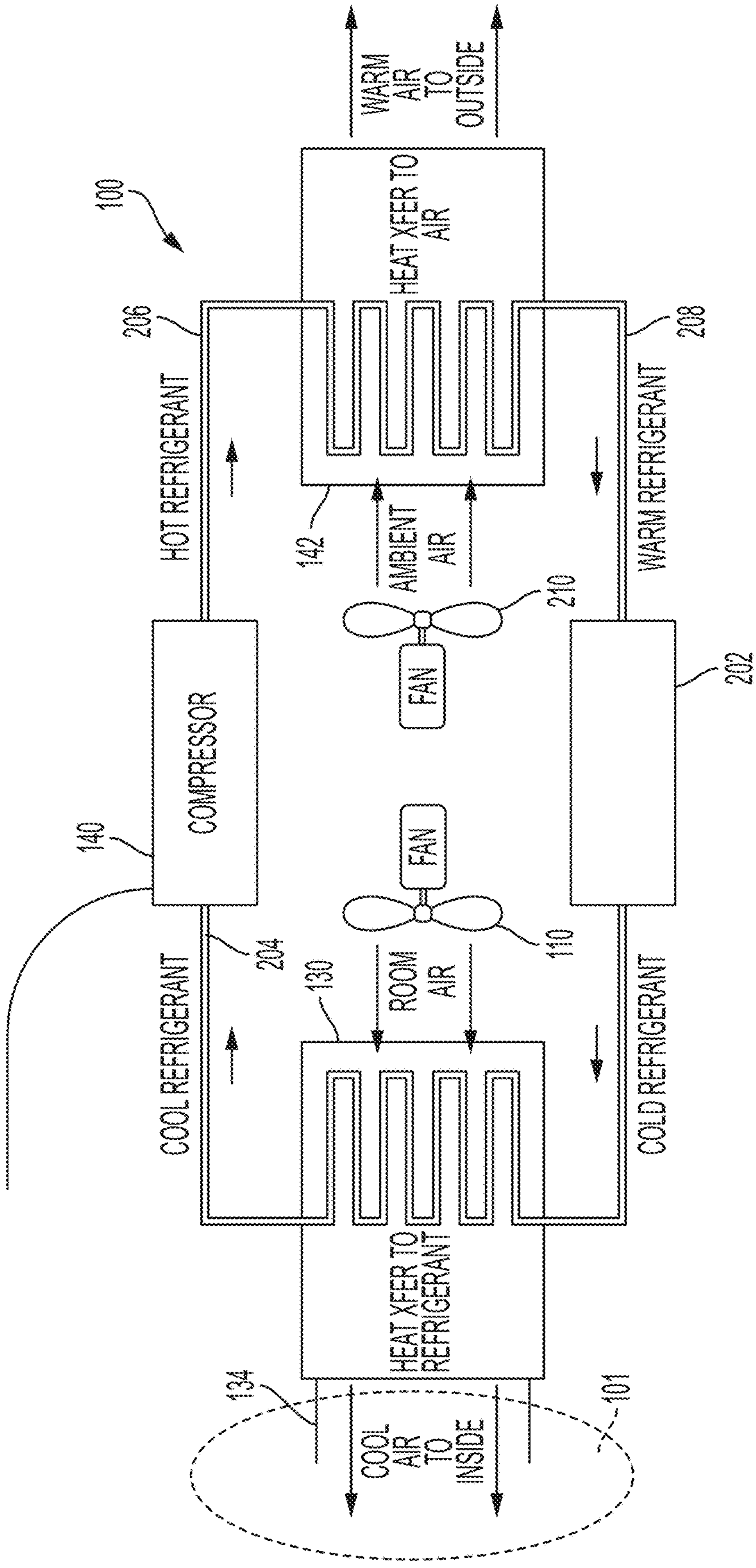

WARM AIR TO OUTSIDE
HEAT XFER TO AIR
100
206
208
HOT REFRIGERANT
WARM REFRIGERANT
142
AMBIENT AIR
210
FAN
202
COMPRESSOR
140
FAN
110
204
ROOM AIR
130
COOL REFRIGERANT
COLD REFRIGERANT
HEAT XFER TO REFRIGERANT
134
101
COOL AIR TO INSIDE

FIG. 2

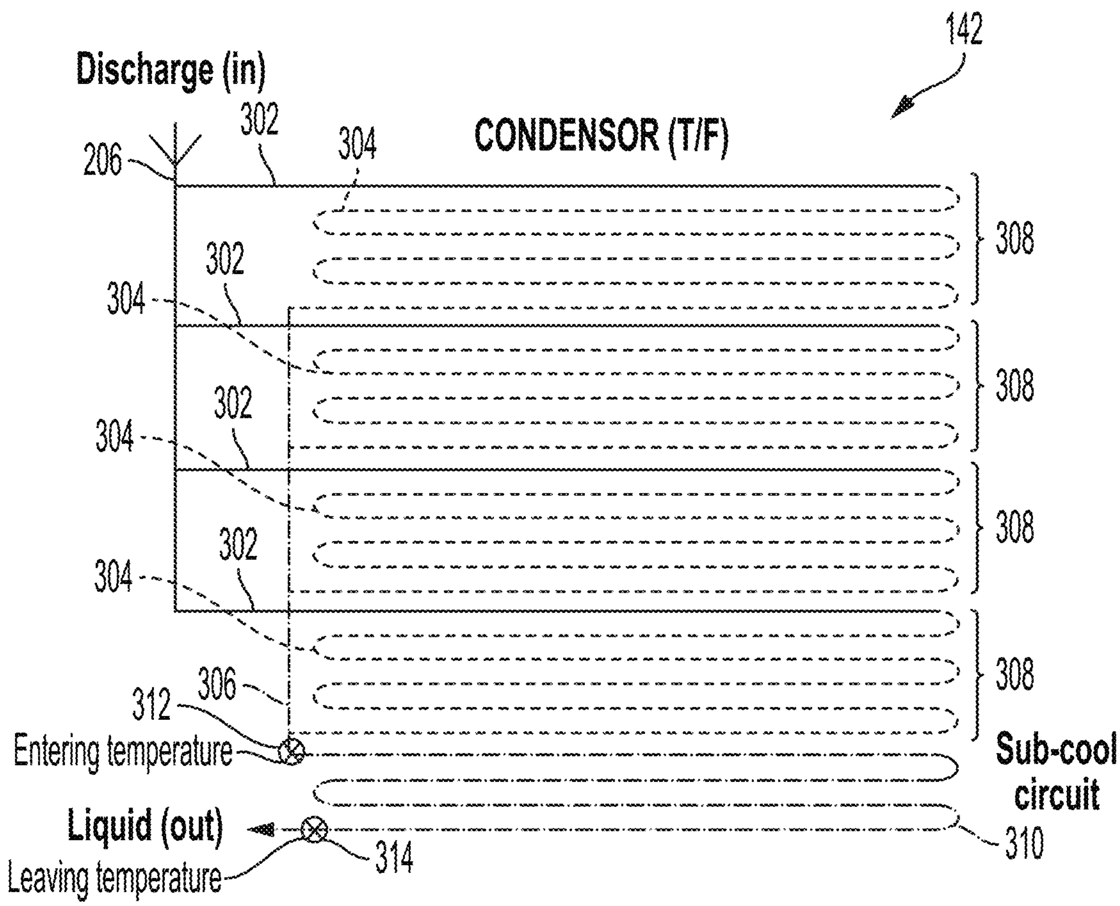
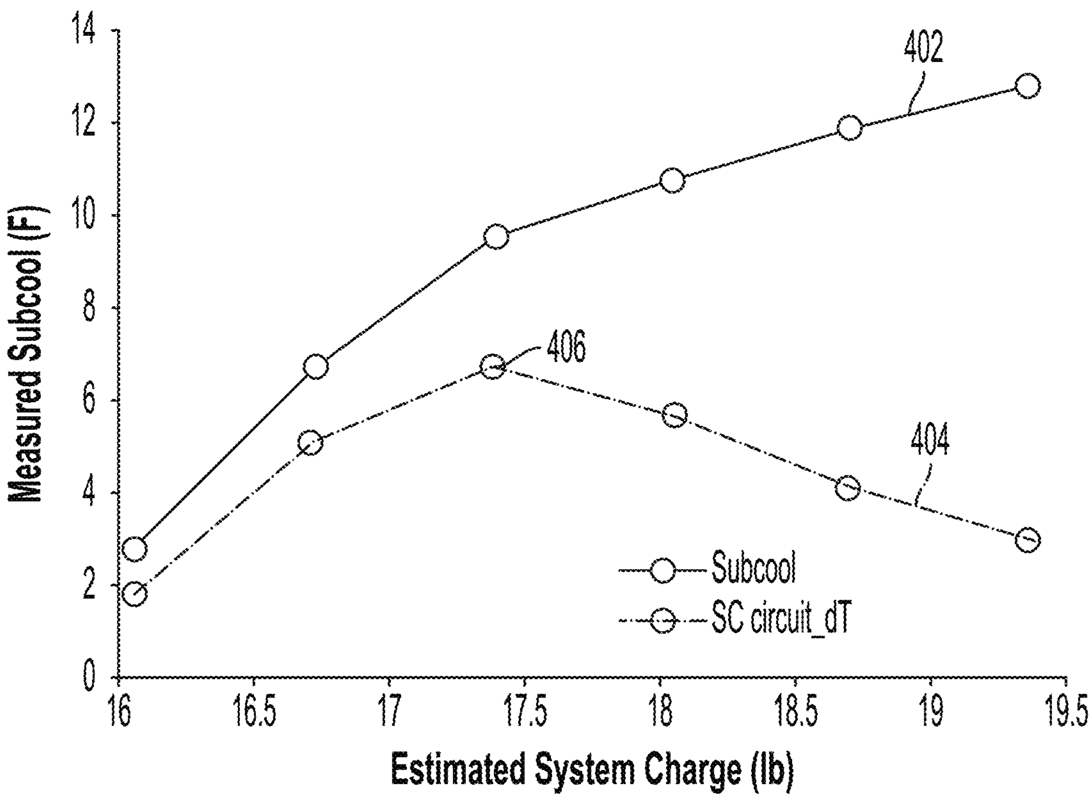

142
Discharge (in)
CONDENSOR (T/F)
206
302
304
308
306
312
Entering temperature
Sub-cool circuit
Liquid (out)
Leaving temperature
314
310

FIG. 3



402
406
404
Subcool
SC circuit_dT
Measured Subcool (F)
Estimated System Charge (lb)
0
2
4
6
8
10
12
14
16
16.5
17
17.5
18
18.5
19
19.5

FIG. 4

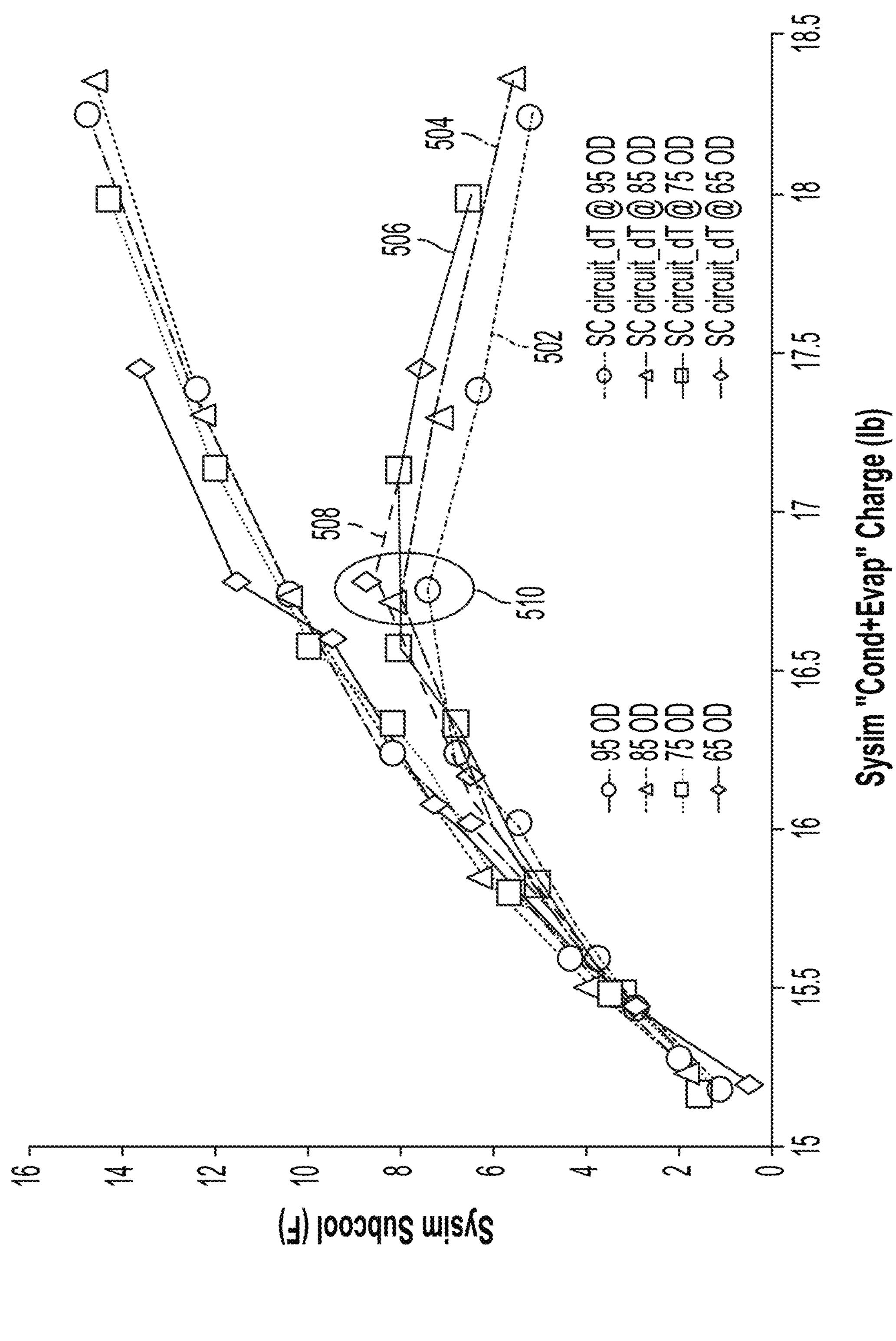

Sysim Subcool (F)
0
2
4
6
8
10
12
14
16
Sysim "Cond+Evap" Charge (lb)
15
15.5
16
16.5
17
17.5
18
18.5
95 OD
85 OD
75 OD
65 OD
SC circuit_dT @ 95 OD
SC circuit_dT @ 85 OD
SC circuit_dT @ 75 OD
SC circuit_dT @ 65 OD
502
504
506
508
510

FIG. 5

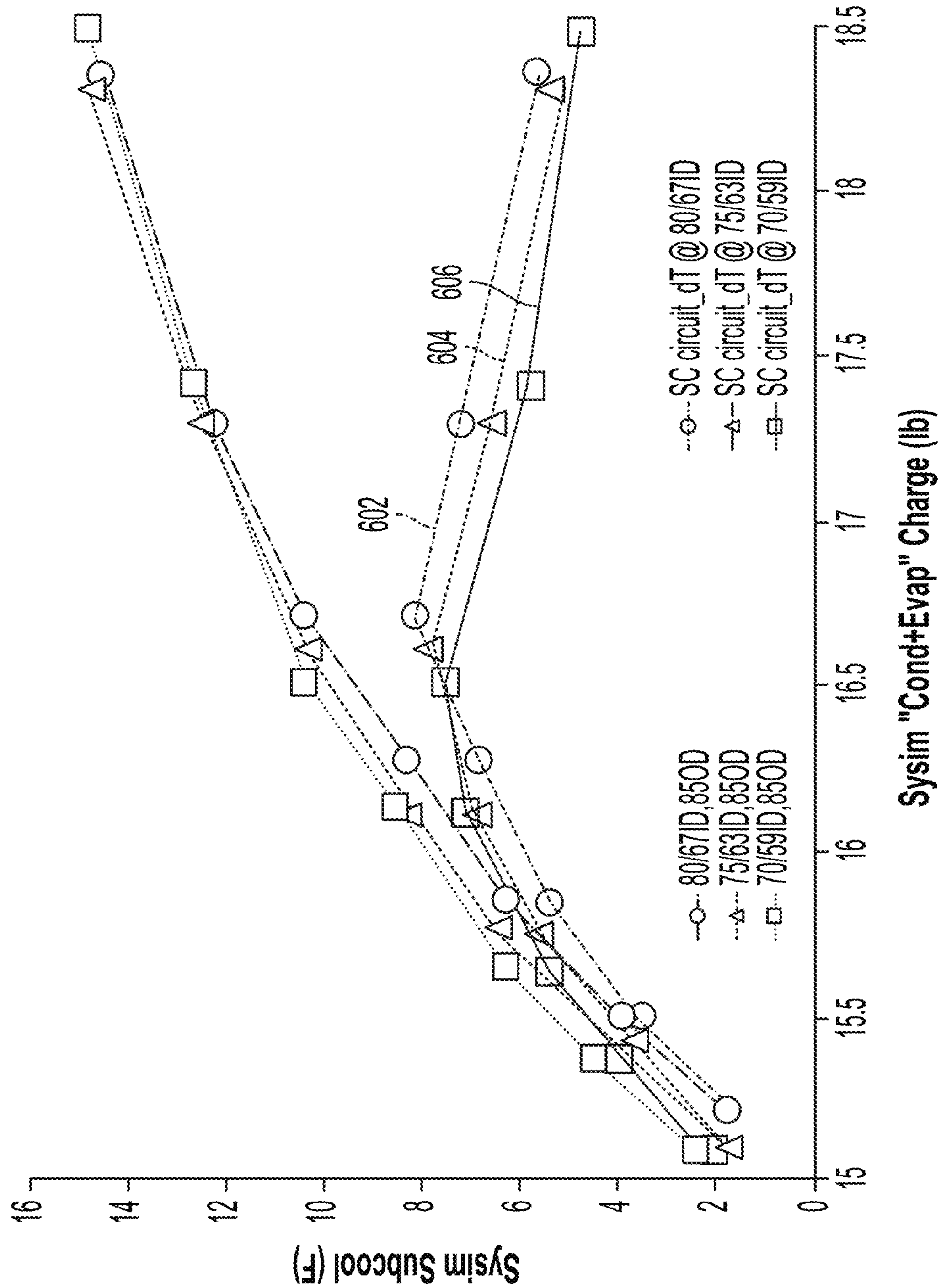

Sysim Subcool (F)
Sysim "Cond+Evap" Charge (lb)
80/67ID,85OD
75/63ID,85OD
70/59ID,85OD
SC circuit_dT @ 80/67ID
SC circuit_dT @ 75/63ID
SC circuit_dT @ 70/59ID
602
604
606
0
2
4
6
8
10
12
14
16
15
15.5
16
16.5
17
17.5
18
18.5

FIG. 6

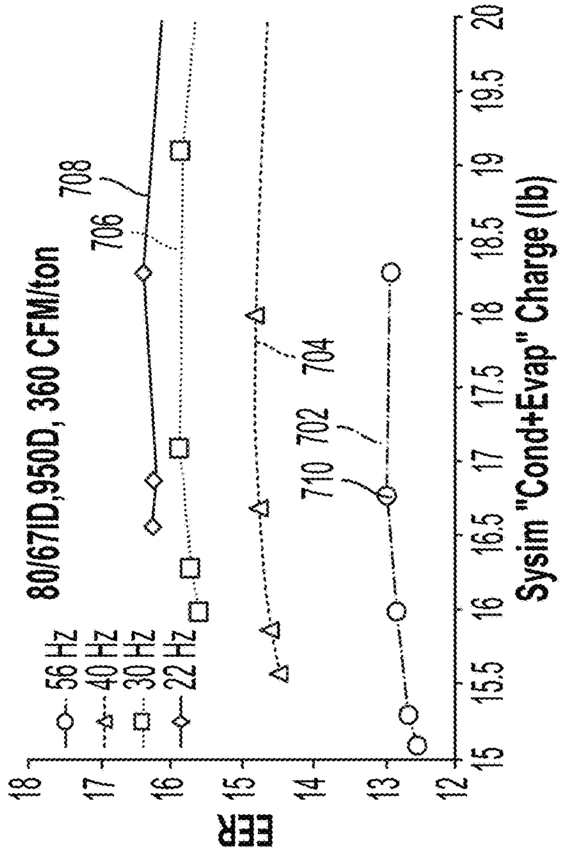

80/67ID,950D, 360 CFM/ton
EER
Sysim "Cond+Evap" Charge (lb)
56 Hz
40 Hz
30 Hz
22 Hz
702
704
706
708
710
18
17
16
15
14
13
12
15
15.5
16
16.5
17
17.5
18
18.5
19
19.5
20

FIG. 7B

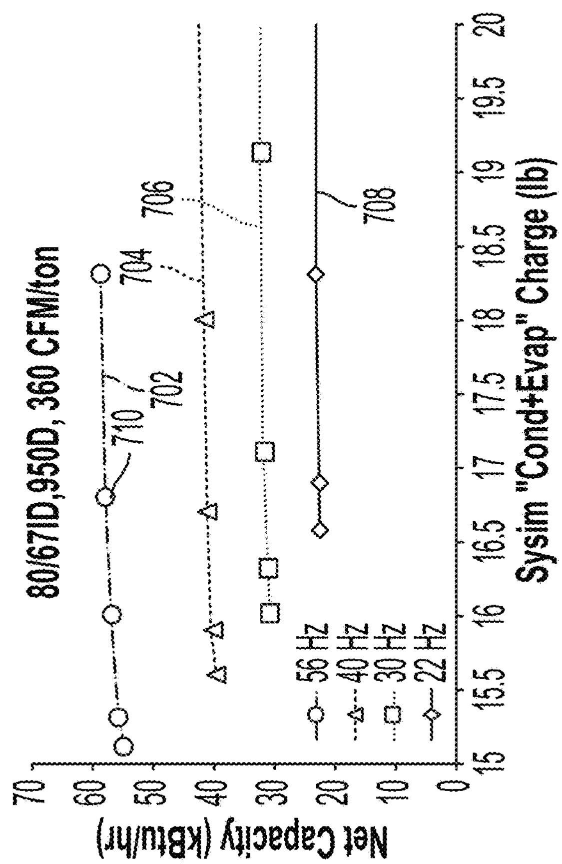

80/67ID,950D, 360 CFM/ton
Net Capacity (kBtu/hr)
Sysim "Cond+Evap" Charge (lb)
56 Hz
40 Hz
30 Hz
22 Hz
702
704
706
708
710
70
60
50
40
30
20
10
0
15
15.5
16
16.5
17
17.5
18
18.5
19
19.5
20

FIG. 7A

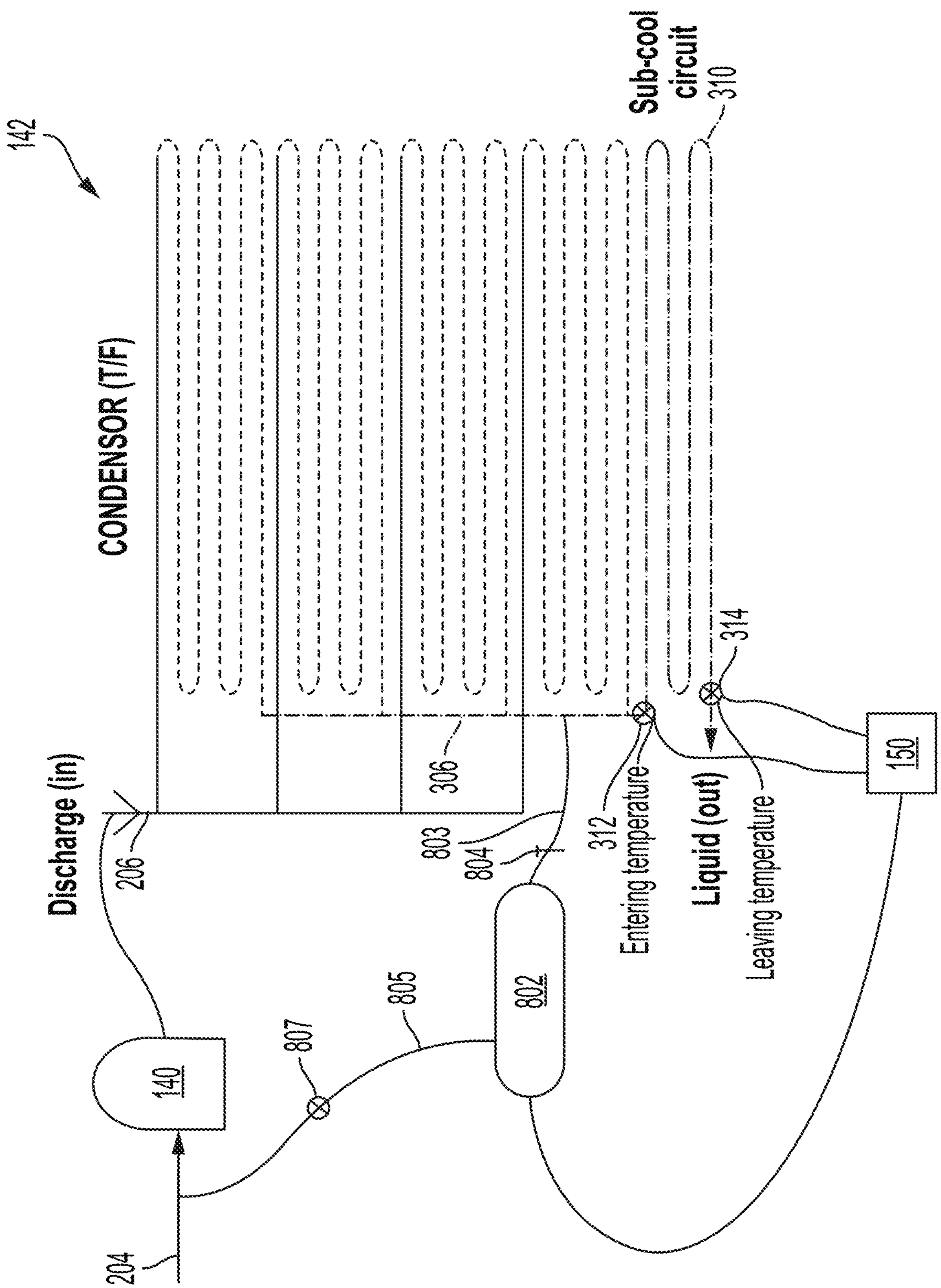

142
CONDENSOR (T/F)
Sub-cool
circuit
310
Discharge (in)
206
306
803
804
312
Entering temperature
Liquid (out)
314
Leaving temperature
150
140
802
805
807
204

FIG. 8

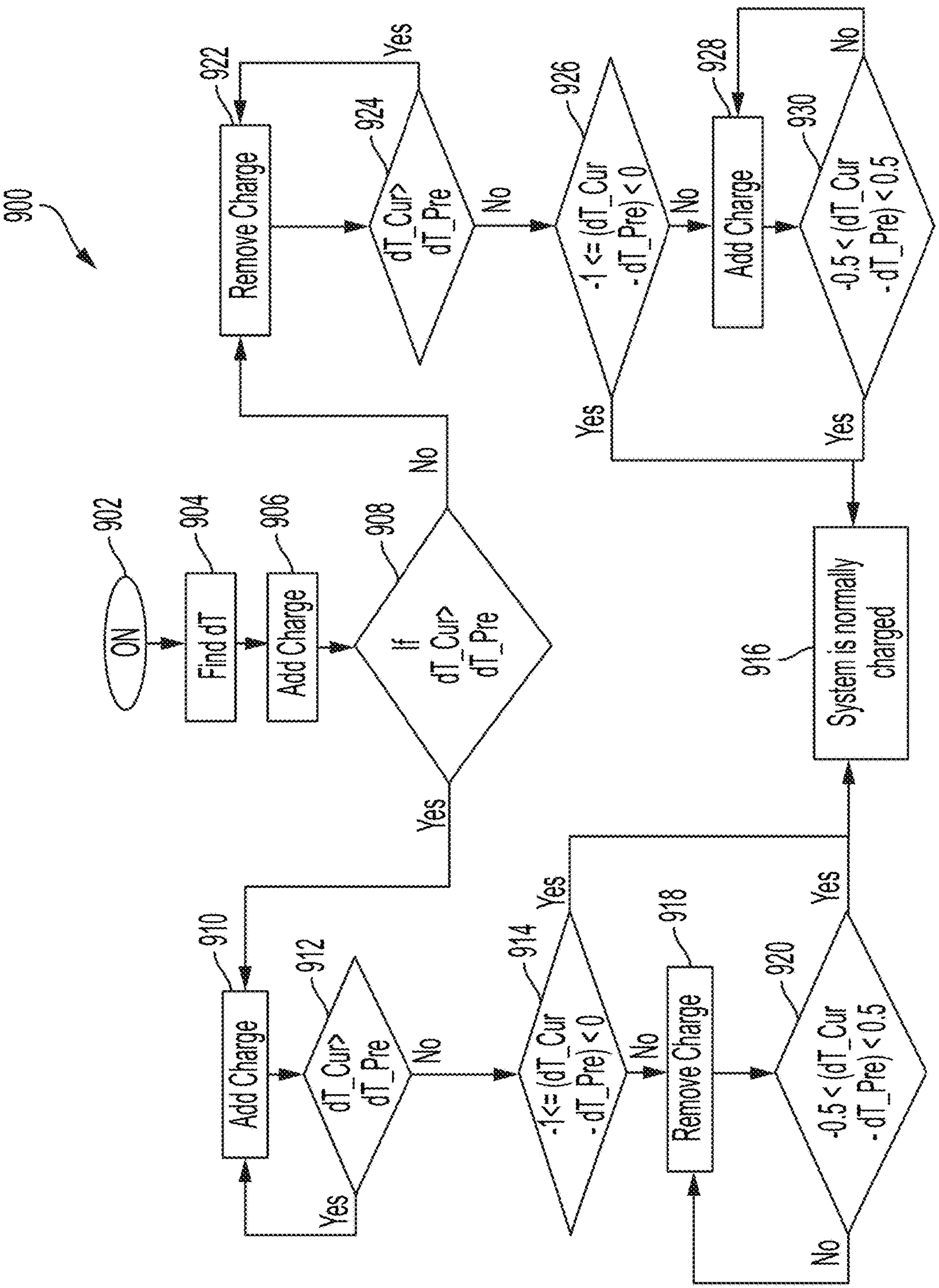

900
ON
902
Find dT
904
Add Charge
906
If
dT_Cur>
dT_Pre
908
Yes
No
Add Charge
910
dT_Cur>
dT_Pre
912
Yes
No
-1<= (dT_Cur
-dT_Pre) < 0
914
Yes
No
Remove Charge
918
-0.5 < (dT_Cur
-dT_Pre) < 0.5
920
Yes
No
System is normally
charged
916
Remove Charge
922
dT_Cur>
dT_Pre
924
Yes
No
-1 <= (dT_Cur
-dT_Pre) < 0
926
Yes
No
Add Charge
928
-0.5 < (dT_Cur
-dT_Pre) < 0.5
930
Yes
No

FIG. 9

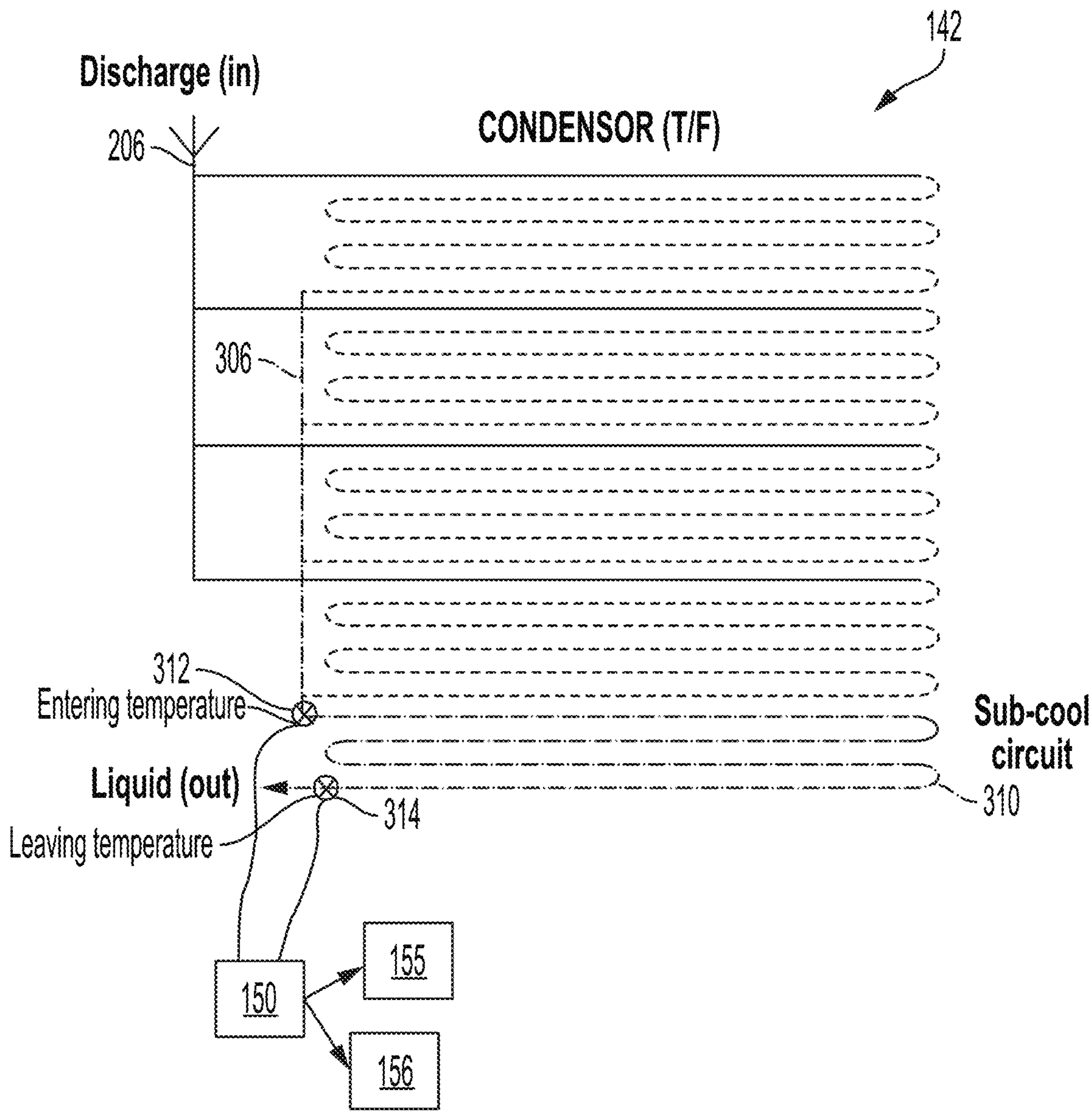

142
Discharge (in)
CONDENSOR (T/F)
206
306
312
Entering temperature
Liquid (out)
314
Leaving temperature
Sub-cool circuit
310
150
155
156

FIG. 10

METHOD AND SYSTEM FOR CHARGE DETERMINATION

TECHNICAL FIELD

The present disclosure relates generally to heating, ventilation, and air conditioning (HVAC) systems and more particularly, but not by way of limitation, to utilizing a temperature-drop measurement across a sub-cooling coil to determine an amount of refrigerant charge in an HVAC system.

BACKGROUND

This section provides background information to facilitate a better understanding of the various aspects of the disclosure. It should be understood that the statements in this section of this document are to be read in this light, and not as admissions of prior art.

HVAC systems are used to regulate environmental conditions within an enclosed space. Typically, HVAC systems have a circulation fan that pulls air from the enclosed space through ducts and pushes the air back into the enclosed space through additional ducts after conditioning the air (e.g., heating, cooling, humidifying, or dehumidifying the air). To direct operation of the circulation fan and other components, HVAC systems include a controller. In addition to directing operation of the HVAC system, the controller may be used to monitor various components, (i.e. equipment) of the HVAC system to determine if the components are functioning properly.

SUMMARY

Various aspects of the disclosure relate to a heating, ventilation, and air conditioning (HVAC) system. The HVAC system includes an evaporator coil and a compressor fluidly coupled to the evaporator coil. A condenser coil is fluidly coupled to the compressor. The condenser coil includes at least one condenser circuit fluidly coupled between a discharge line and an exit manifold. A sub-cool circuit is fluidly coupled between the exit manifold and a liquid line. A first temperature sensor is disposed at an entrance to the sub-cool circuit. A second temperature sensor is disposed at an exit to the sub-cool circuit. An HVAC controller is operatively coupled to the first temperature sensor and the second temperature sensor. The HVAC controller is configured to determine a temperature difference across the sub-cool circuit.

Various aspects of the disclosure relate to a condenser coil. The condenser coil includes at least one condenser circuit fluidly coupled between a discharge line and an exit manifold. A sub-cool circuit is fluidly coupled between the exit manifold and a liquid line. A first temperature sensor is disposed at an entrance to the sub-cool circuit. A second temperature sensor is disposed at an exit to the sub-cool circuit. An HVAC controller is operatively coupled to the first temperature sensor and the second temperature sensor. The HVAC controller is configured to determine a temperature difference across the sub-cool circuit. Responsive to the determined temperature difference, the HVAC controller determines if an HVAC system is one of undercharged or overcharged.

Various aspects of the disclosure relate to a method of charge management for an HVAC system. The method includes determining, with a first temperature sensor and a second temperature sensor, a temperature difference across a sub-cool circuit. A refrigerant charge is added to the HVAC system. Utilizing an HVAC controller, it is assessed if the refrigerant charge causes the temperature difference to increase or decrease. Responsive to a determination that the refrigerant charge causes the temperature difference to increase, additional refrigerant charge is added to the HVAC system. Responsive to a determination that the refrigerant charge causes the temperature difference to decrease, refrigerant charge is removed from the HVAC system.

This summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosure is best understood from the following detailed description when read with the accompanying figures. It is emphasized that, in accordance with standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of various features may be arbitrarily increased or reduced for clarity of discussion.

FIG. **1** is a block diagram of an exemplary HVAC system;

FIG. **2** is a schematic diagram of an exemplary HVAC system according to aspects of the disclosure;

FIG. **3** is a schematic diagram of a condenser coil according to aspects of the disclosure;

FIG. **4** is a graph illustrating how sub-cool temperature varies with an amount of refrigerant charge according to aspects of the disclosure;

FIG. **5** is a graph illustrating how sub-cool temperature varies with an amount of refrigerant charge at various outdoor temperatures according to aspects of the disclosure;

FIG. **6** is a graph illustrating how sub-cool temperature varies with an amount of refrigerant charge at various indoor temperatures according to aspects of the disclosure:

FIGS. **7**A-**7**B are graphs illustrating variation of net capacity and energy efficiency ratio with an amount of refrigerant charge according to aspects of the disclosure;

FIG. **8** is a schematic diagram of an active charge management system according to aspects of the disclosure;

FIG. **9** is a flow diagram illustrating a process for active charge management according to aspects of the disclosure; and

FIG. **10** is a schematic diagram of a loss-of-charge detection system according to aspects of the disclosure.

DETAILED DESCRIPTION

Various embodiments will now be described more fully with reference to the accompanying drawings. The disclosure may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein.

FIG. **1** illustrates an HVAC system **100**. In a typical embodiment, the HVAC system **100** is a networked HVAC system that is configured to condition air via, for example, heating, cooling, humidifying, or dehumidifying air within an enclosed space **101**. In a typical embodiment, the enclosed space **101** is, for example, a house, an office building, a warehouse, and the like. Thus, the HVAC system **100** can be a residential system or a commercial system such as, for example, a roof top system. For exemplary illustration, the HVAC system **100** as illustrated in FIG. **1** includes various components; however, in other embodiments, the

HVAC system **100** may include additional components that are not illustrated but typically included within HVAC systems.

The HVAC system **100** includes a circulation fan **110**, a gas heat **120**, electric heat **122** typically associated with the circulation fan **110**, and an evaporator coil **130**, also typically associated with the circulation fan **110**. The circulation fan **110**, the gas heat **120**, the electric heat **122**, and the evaporator coil **130** are collectively referred to as an "indoor unit" **148**. In a typical embodiment, the indoor unit **148** is located within, or in close proximity to, the enclosed space **101**. The HVAC system **100** also includes a compressor **140** and an associated condenser coil **142**, which are typically referred to as an "outdoor unit" **144**. In various embodiments, the outdoor unit **144** is, for example, a rooftop unit or a ground-level unit. A rooftop unit is a type of HVAC system where the indoor unit **148** and the outdoor unit **144** are integral within a common housing. The compressor **140** and the associated condenser coil **142** are connected to an associated evaporator coil **130** by a refrigerant line **146**. In a typical embodiment, the compressor **140** is, for example, a single-stage compressor or a multi-stage compressor. The circulation fan **110**, sometimes referred to as a blower, is configured to operate at different capacities (i.e., variable motor speeds) to circulate air through the HVAC system **100**, whereby the circulated air is conditioned and supplied to the enclosed space **101**.

Still referring to FIG. **1**, the HVAC system **100** includes an HVAC controller **150** that is configured to control operation of the various components of the HVAC system **100** such as, for example, the circulation fan **110**, the gas heat **120**, the electric heat **122**, and the compressor **140** to regulate the environment of the enclosed space **101**. In some embodiments, the HVAC system **100** can be a zoned system. In such embodiments, the HVAC system **100** includes a zone controller **180**, dampers **185**, and a plurality of environment sensors **160**. In a typical embodiment, the HVAC controller **150** cooperates with the zone controller **180** and the dampers **185** to regulate the environment of the enclosed space **101**.

The HVAC controller **150** may be an integrated controller or a distributed controller that directs operation of the HVAC system **100**. In a typical embodiment, the HVAC controller **150** includes an interface to receive, for example, thermostat calls, temperature setpoints, blower control signals, environmental conditions, and operating mode status for various zones of the HVAC system **100**. For example, in a typical embodiment, the environmental conditions may include indoor temperature and relative humidity of the enclosed space **101**. In a typical embodiment, the HVAC controller **150** also includes a processor and a memory to direct operation of the HVAC system **100** including, for example, a speed of the circulation fan **110**.

Still referring to FIG. **1**, in some embodiments, the plurality of environment sensors **160** are associated with the HVAC controller **150** and also optionally associated with a user interface **170**. The plurality of environment sensors **160** provide environmental information within a zone or zones of the enclosed space **101** such as, for example, temperature and humidity of the enclosed space **101** to the HVAC controller **150**. The plurality of environment sensors **160** may also send the environmental information to a display of the user interface **170**. In some embodiments, the user interface **170** provides additional functions such as, for example, operational, diagnostic, status message display, and a visual interface that allows at least one of an installer, a user, a support entity, and a service provider to perform actions with respect to the HVAC system **100**. In some embodiments, the user interface **170** is, for example, a thermostat of the HVAC system **100**. In other embodiments, the user interface **170** is associated with at least one sensor of the plurality of environment sensors **160** to determine the environmental condition information and communicate that information to the user. The user interface **170** may also include a display, buttons, a microphone, a speaker, or other components to communicate with the user. Additionally, the user interface **170** may include a processor and memory that is configured to receive user-determined parameters such as, for example, a relative humidity of the enclosed space **101**, and calculate operational parameters of the HVAC system **100** as disclosed herein.

In a typical embodiment, the HVAC system **100** is configured to communicate with a plurality of devices such as, for example, a monitoring device **156**, a communication device **155**, and the like. In a typical embodiment, the monitoring device **156** is not part of the HVAC system. For example, the monitoring device **156** is a server or computer of a third party such as, for example, a manufacturer, a support entity, a service provider, and the like. In other embodiments, the monitoring device **156** is located at an office of, for example, the manufacturer, the support entity, the service provider, and the like.

In a typical embodiment, the communication device **155** is a non-HVAC device having a primary function that is not associated with HVAC systems. For example, non-HVAC devices include mobile-computing devices that are configured to interact with the HVAC system **100** to monitor and modify at least some of the operating parameters of the HVAC system **100**. Mobile computing devices may be, for example, a personal computer (e.g., desktop or laptop), a tablet computer, a mobile device (e.g., smart phone), and the like. In a typical embodiment, the communication device **155** includes at least one processor, memory and a user interface, such as a display. One skilled in the art will also understand that the communication device **155** disclosed herein includes other components that are typically included in such devices including, for example, a power supply, a communications interface, and the like.

The zone controller **180** is configured to manage movement of conditioned air to designated zones of the enclosed space **101**. Each of the designated zones include at least one conditioning or demand unit such as, for example, the gas heat **120** and at least one user interface **170** such as, for example, the thermostat. The zone-controlled HVAC system **100** allows the user to independently control the temperature in the designated zones. In a typical embodiment, the zone controller **180** operates electronic dampers **185** to control air flow to the zones of the enclosed space **101**.

In some embodiments, a data bus **190**, which in the illustrated embodiment is a serial bus, couples various components of the HVAC system **100** together such that data is communicated therebetween. In a typical embodiment, the data bus **190** may include, for example, any combination of hardware, software embedded in a computer readable medium, or encoded logic incorporated in hardware or otherwise stored (e.g., firmware) to couple components of the HVAC system **100** to each other. As an example and not by way of limitation, the data bus **190** may include an Accelerated Graphics Port (AGP) or other graphics bus, a Controller Area Network (CAN) bus, a front-side bus (FSB), a HYPERTRANSPORT (HT) interconnect, an INFINIBAND interconnect, a low-pin-count (LPC) bus, a memory bus, a Micro Channel Architecture (MCA) bus, a Peripheral Component Interconnect (PCI) bus, a PCI-Express (PCI-X) bus, a serial advanced technology attachment (SATA) bus, a

Video Electronics Standards Association local (VLB) bus, or any other suitable bus or a combination of two or more of these. In various embodiments, the data bus **190** may include any number, type, or configuration of data buses **190**, where appropriate. In particular embodiments, one or more data buses **190** (which may each include an address bus and a data bus) may couple the HVAC controller **150** to other components of the HVAC system **100**. In other embodiments, connections between various components of the HVAC system **100** are wired. For example, conventional cable and contacts may be used to couple the HVAC controller **150** to the various components. In some embodiments, a wireless connection is employed to provide at least some of the connections between components of the HVAC system such as, for example, a connection between the HVAC controller **150** and the circulation fan **110** or the plurality of environment sensors **160**.

FIG. **2** is a schematic diagram of the HVAC system **100**. The HVAC system **100** includes the evaporator coil **130**, the condenser coil **142**, the compressor **140**, and a metering device **202**. During operation, the circulation fan **110** circulates air around the evaporator coil **130**. In various embodiments, the compressor **140** is, for example, a single-stage compressor, a multi-stage compressor, a single-speed compressor, or a multi-speed compressor. The circulation fan **110**, sometimes referred to as a blower, may, in various embodiments, be configured to operate at different capacities (i.e., variable motor speeds) to circulate air through the HVAC system **100**, whereby the circulated air is conditioned and supplied to the enclosed space **101**. In a typical embodiment, the metering device **202** is, for example, a thermostatic expansion valve or a throttling valve. The evaporator coil **130** is fluidly coupled to the compressor **140** via a suction line **204**. The compressor **140** is fluidly coupled to the condenser coil **142** via a discharge line **206**. The condenser coil **142** is fluidly coupled to the metering device **202** via a liquid line **208**.

Still referring to FIG. **2**, during operation, low-pressure, low-temperature refrigerant is circulated through the evaporator coil **130**. The refrigerant is initially in a liquid/vapor state. In a typical embodiment, the refrigerant is, for example, R-22, R-134a, R-410A, R-744, or any other suitable type of refrigerant as dictated by design requirements. Air from within the enclosed space **101**, which is typically warmer than the refrigerant, is circulated around the evaporator coil **130** by the circulation fan **110**. In a typical embodiment, the refrigerant begins to boil after absorbing heat from the air and changes state to a low-pressure, low-temperature, super-heated vapor refrigerant. Saturated vapor, saturated liquid, and saturated fluid refer to a thermodynamic state where a liquid and its vapor exist in approximate equilibrium with each other. Super-heated fluid and super-heated vapor refer to a thermodynamic state where a vapor is heated above a saturation temperature of the vapor. Sub-cooled fluid and sub-cooled liquid refers to a thermodynamic state where a liquid is cooled below the saturation temperature of the liquid.

The low-pressure, low-temperature, super-heated vapor refrigerant is introduced into the compressor **140** via the suction line **204**. In a typical embodiment, the compressor **140** increases the pressure of the low-pressure, low-temperature, super-heated vapor refrigerant and, by operation of the ideal gas law, also increases the temperature of the low-pressure, low-temperature, super-heated vapor refrigerant to form a high-pressure, high-temperature, superheated vapor refrigerant. The high-pressure, high-temperature, superheated vapor refrigerant leaves the compressor **140** via the discharge line **206** and enters the condenser coil **142**.

Still referring to FIG. **2**, outside air is circulated around the condenser coil **142** by a condenser fan **210**. The outside air is typically cooler than the high-pressure, high-temperature, superheated vapor refrigerant present in the condenser coil **142**. Thus, heat is transferred from the high-pressure, high-temperature, superheated vapor refrigerant to the outside air. Removal of heat from the high-pressure, high-temperature, superheated vapor refrigerant causes the high-pressure, high-temperature, superheated vapor refrigerant to condense and change from a vapor state to a high-pressure, sub-cooled liquid state. After leaving the condenser coil **142**, the high-pressure, sub-cooled refrigerant is at a temperature close to an ambient outside air temperature. The high-pressure, sub-cooled liquid refrigerant leaves the condenser coil **142** via the liquid line **208** and enters the metering device **202**.

In the metering device **202**, the pressure of the high-pressure, sub-cooled liquid refrigerant is abruptly reduced. In various embodiments where the metering device **202** is, for example, a thermostatic expansion valve, the metering device **202** reduces the pressure of the high-pressure, sub-cooled liquid refrigerant by regulating an amount of refrigerant that travels to the evaporator coil **130**. Abrupt reduction of the pressure of the high-pressure, sub-cooled liquid refrigerant causes sudden, rapid, evaporation of a portion of the high-pressure, sub-cooled liquid refrigerant, commonly known as "flash evaporation." The flash evaporation lowers the temperature of the resulting liquid/vapor refrigerant mixture to a temperature lower than a temperature of the air in the enclosed space **101**. The liquid/vapor refrigerant mixture leaves the metering device **202** and returns to the evaporator coil **130**.

FIG. **3** is a schematic diagram of the condenser coil **142**. The condenser coil **142** is fed from the compressor **140** by the discharge line **206**. The condenser coil **142** includes at least one inlet branch **302**. The at least one inlet branch **302** is fluidly coupled to the discharge line **206**. The at least one inlet branch **302** directs the high-pressure, high-temperature, superheated vapor refrigerant through a series of condenser loops **304** and into an exit manifold **306**. The at least one inlet branch **302** and the series of condenser loops **304** define a condenser circuit **308**. By way of example, the condenser coil **142**, shown in FIG. **3**, includes four condenser circuits **308**; however, in other embodiments, the condenser coil **142** may include a single condenser circuit **308**, between one and four condenser circuits **308**, or more than four condenser circuits **308**.

Still referring to FIG. **3**, the exit manifold **306** directs the refrigerant into a sub-cool circuit **310**. In the sub-cool circuit **310**, the refrigerant is further cooled and changes state from a saturated liquid/vapor to a sub-cooled liquid. In various embodiments, the sub-cool circuit **310** facilitates state change of the refrigerant to a sub-cooled liquid under all conditions. Liquid refrigerant exits the condenser coil **142** via the liquid line **208**. A first temperature sensor **312** is disposed in the exit manifold **306** at an entrance to the sub-cool circuit **310** and measures a temperature of refrigerant entering the sub-cool circuit **310**. A second temperature sensor **314** is disposed at an exit of the sub-cool circuit **310** and measures a temperature of refrigerant leaving the sub-cool circuit **310**. Thus, the first temperature sensor **312** and the second temperature sensor **314** facilitate measurement of a temperature difference across the sub-cool circuit **310**. In various embodiments, the first temperature sensor **312** and the second temperature sensor **314** may be, for example, a thermometer, a thermocouple, a thermistor, a resistance temperature detector (RTD), an infrared sensor, or a semiconductor sensor.

FIG. **4** is a graph illustrating variation of sub-cool temperature with an amount of refrigerant charge. Line **402** illustrates variation of liquid sub-cool temperature. Liquid sub-cool temperature is defined as the difference between a saturated liquid temperature and the liquid temperature. As illustrated in FIG. **4**, the liquid sub-cool temperature continues to rise with the addition of refrigerant charge. Line **404** illustrates variation of temperature difference across the sub-cool circuit **310**. As illustrated in FIG. **4**, the temperature difference across the sub-cool circuit **310** increases with the addition of refrigerant charge to a maximum temperature difference **406**. Beyond the maximum temperature difference **406**, the temperature difference across the sub-cool circuit decreases with the addition of more refrigerant charge. The maximum temperature difference **406** indicates the optimal amount of refrigerant charge in to the HVAC system **100**. By of example, in the embodiment illustrated in FIG. **4**, the optimal amount of refrigerant charge is approximately 17.3 lbs of refrigerant.

FIG. **5** is a graph illustrating variation of temperature difference across the sub-cool circuit **310** with an amount of refrigerant charge at various outdoor temperatures. Line **502** illustrates temperature difference across the sub-cool circuit **310** at an outdoor temperature of 95° F. Line **504** illustrates temperature difference across the sub-cool circuit **310** at an outdoor temperature of 85° F. Line **506** illustrates temperature difference across the sub-cool circuit **310** at an outdoor temperature of 75° F. Line **508** illustrates temperature difference across the sub-cool circuit **310** at an outdoor temperature of 65° F. Lines **502**, **504**, **506**, and **508** demonstrate minimal variations in the amount of refrigerant charge that corresponds to the maximum temperature difference **510** across the sub-cool circuit **310**. Thus, FIG. **5** illustrates that the optimal amount of refrigerant charge is largely unaffected by outdoor temperature conditions.

FIG. **6** is a graph illustrating variation of temperature difference across the sub-cool circuit **310** with an amount of refrigerant charge at various indoor temperatures. Line **602** illustrates temperature difference across the sub-cool circuit **310** at an indoor dry-bulb temperature of 80° F. and an indoor wet-bulb temperature of 67° F. (approximately 50% relative humidity). Line **604** illustrates temperature difference across the sub-cool circuit **310** at an indoor dry-bulb temperature of 75° F. and an indoor wet-bulb temperature of 63° F. (approximately 50% relative humidity). Line **606** illustrates temperature difference across the sub-cool circuit **310** at an indoor dry-bulb temperature of 70° F. and an indoor wet-bulb temperature of 59° F. (approximately 50% relative humidity). Lines **602**, **604**, and **606** demonstrate minimal variations in the amount of refrigerant charge that corresponds to the maximum temperature difference **608** across the sub-cool circuit **310**. Thus, FIG. **6** illustrates that the optimal amount of refrigerant charge is largely unaffected by indoor temperature conditions.

FIGS. **7A-7B** are graphs illustrating variation of net capacity and energy efficiency ratio with an amount of refrigerant charge. Line **702** illustrates variation of net capacity and energy efficiency ratio when the compressor **140** is operating at 56 Hz. Line **704** illustrates variation of net capacity and energy efficiency ratio when the compressor **140** is operating at 40 Hz. Line **706** illustrates variation of net capacity and energy efficiency ratio when the compressor **140** is operating at 30 Hz. Line **708** illustrates variation of net capacity and energy efficiency ratio when the compressor **140** is operating at 22 Hz. Point **710** illustrates an optimal charge level yielding peak net capacity and efficiency of the HVAC system **100**.

FIG. **8** is a schematic diagram of an active charge management system **800**. The active charge management system **800** includes the condenser coil **142** and the sub-cool circuit **310** described above with respect to FIG. **3**. The first temperature sensor **312** and the second temperature sensor **314** are electrically coupled to the HVAC controller **150**. A refrigerant reservoir **802** is fluidly coupled to the exit manifold **306** via a removal line **803**. The refrigerant reservoir **802** is fluidly coupled to the suction line **204** via a filling line **805**. A first valve **804** such as, for example, a solenoid valve, is disposed in the removal line **803** between the refrigerant reservoir **802** and the exit manifold **306** and, when closed, prevents flow of refrigerant between the exit manifold **306** and the refrigerant reservoir **802**. The first valve **804** is electrically coupled to the HVAC controller **150**. A second valve **807** such as, for example, a solenoid valve, is disposed in the filling line **805** between the refrigerant reservoir **802** and the suction line **204** and, when closed, prevents flow of refrigerant between the refrigerant reservoir **802** and the suction line **204**. The second valve **807** is electrically coupled to the HVAC controller **150**.

Still referring to FIG. **8**, during operation, the first temperature sensor **312** and the second temperature sensor **314** transmit measurements of liquid refrigerant temperature at an inlet to the sub-cool circuit **310** and at an exit from the sub-cool circuit **310**, respectively. The HVAC controller **150** utilizes the measurements from the first temperature sensor **312** and the second temperature sensor **314** to calculate a temperature difference across the sub-cool circuit **310**.

FIG. **9** is a flow diagram illustrating a process **900** for active charge management. The process **900** begins at step **902**. At step **904**, the HVAC controller **150** determines a temperature difference across the sub-cool circuit **310** based on temperature measurements from the first temperature sensor **312** and the second temperature sensor **314**. At step **906**, the HVAC controller directs the second valve **807** to open for a period of time to allow a fixed amount of additional refrigerant to be introduced from the refrigerant reservoir **802** to the suction line **204**. In various embodiments, the suction line **204** is at a lower pressure than the refrigerant reservoir **802** thereby inducing flow of refrigerant from the refrigerant reservoir **802** to the suction line **204** when the second valve **807** is open. At step **908**, it is determined if the temperature difference across the sub-cool circuit **310** is greater than the temperature difference measured in step **904**.

Still referring to FIG. **9**, if it is determined in step **908** that the temperature difference across the sub-cool circuit is greater than the temperature difference measured in step **904**, then the HVAC system is undercharged and the process **900** proceeds to step **910**. At step **910**, the HVAC controller directs the second valve **807** to open for a period of time to allow a fixed amount of additional refrigerant to be introduced from the refrigerant reservoir **802** to the suction line **204**. In various embodiments, the suction line **204** is at a lower pressure than the refrigerant reservoir **802** thereby inducing flow of refrigerant from the refrigerant reservoir **802** to the suction line **204** when the second valve **807** is open. At step **912**, it is determined if the temperature difference across the sub-cool circuit is greater than the temperature difference measured at step **908**. If, at step **912**, it is determined that the temperature difference across the sub-cool circuit is greater than the temperature difference measured at step **908**, the HVAC system remains undercharged and the process **900** returns to step **910**. If, at step **912**, it is determined that the temperature difference across the sub-cool circuit **310** is not greater than the temperature difference measured at step **908**, then the process **900** proceeds to step **914**. At step **914**, it is determined if the difference between the temperature difference across the sub-cool circuit **310** and the temperature difference measured at step **908** is between −1 and 0. If it is determined at step **914** that the difference is between −1 and 0, then the HVAC system **100** is normally charged and the process **900** ends at step **916**. If it is determined at step **914** that the difference is not between −1 and 0, then the HVAC system is overcharged and the process **900** proceeds to step **918**. At step **918**, the HVAC controller **150** directs the first valve **804** to open in an effort to remove refrigerant from the exit manifold **306** to the refrigerant reservoir **802**. In various embodiments, the exit manifold **306** is at a higher pressure than the refrigerant reservoir **802** thereby inducing flow of refrigerant from the exit manifold **306** into the refrigerant reservoir **802** when the first valve **804** is open. At step **920**, it is determined if the difference between the temperature difference across sub-cool circuit **310** and the temperature difference measured at step **914** is between −0.5 and 0.5. If, at step **920**, it is determined that the difference is between −0.5 and 0.5, then the HVAC system **100** is normally charged and the process **900** ends at step **916**. If, at step **920**, it is determined that the difference is not between −0.5 and 0.5, then the process **900** returns to step **918**.

Still referring to FIG. **9**, if it is determined in step **908** that the temperature difference across the sub-cool circuit is not greater than the temperature difference measured in step **904**, then the HVAC system is overcharged and the process **900** proceeds to step **922**. At step **922**, the HVAC controller directs the first valve **804** to open for a period of time to allow a fixed amount of refrigerant to be removed from the exit manifold **306** to the refrigerant reservoir **802**. In various embodiments, the exit manifold **306** is at a higher pressure than the refrigerant reservoir **802** thereby inducing flow of refrigerant from the exit manifold **306** into the refrigerant reservoir **802** when the first valve **804** is open. At step **924**, it is determined if the temperature difference across the sub-cool circuit is greater than the temperature difference measured at step **908**. If, at step **924**, it is determined that the temperature difference across the sub-cool circuit **310** is greater than the temperature difference measured at step **908**, the HVAC system remains overcharged and the process **900** returns to step **922**. If, at step **924**, it is determined that the temperature difference across the sub-cool circuit **310** is not greater than the temperature difference measured at step **908**, then the process **900** proceeds to step **926**. At step **926**, it is determined if the difference between the temperature difference across the sub-cool circuit **310** and the temperature difference measured at step **908** is between −1 and 0. If it is determined at step **926** that the difference is between −1 and 0, then the HVAC system **100** is normally charged and the process **900** ends at step **916**. If it is determined at step **926** that the difference is not between −1 and 0, then the HVAC system is undercharged and the process **900** proceeds to step **928**. At step **928**, the HVAC controller **150** directs the second valve **807** to open in an effort to add refrigerant from the refrigerant reservoir **802** to the suction line **204**. In various embodiments, the suction line **204** is at a lower pressure than the refrigerant reservoir **802** thereby inducing flow of refrigerant from the refrigerant reservoir **802** to the suction line **204** when the second valve **807** is open. At step **930**, it is determined if the difference between the temperature difference across sub-cool circuit **310** and the temperature difference measured at step **926** is between −0.5 and 0.5. If, at step **930**, it is determined that the difference is between −0.5 and 0.5, then the HVAC system **100** is normally charged and the process **900** ends at step **916**. If, at step **930**, it is determined that the difference is not between −0.5 and 0.5, then the process **900** returns to step **928**.

FIG. **10** is a schematic diagram of a loss-of-charge detection system **1000**. The loss-of-charge detection system **1000** includes the condenser coil **142** and the sub-cool circuit **310** described above with respect to FIG. **3**. The first temperature sensor **312** and the second temperature sensor **314** are electrically coupled to the HVAC controller **150**. During operation, the first temperature sensor **312** and the second temperature sensor **314** transmit measurements of liquid refrigerant temperature at an inlet to the sub-cool circuit **310** and at an exit from the sub-cool circuit **310**, respectively. The HVAC controller **150** utilizes the measurements from the first temperature sensor **312** and the second temperature sensor **314** to calculate a temperature difference across the sub-cool circuit **310**. If the HVAC controller **150** detects a decrease in the magnitude of the temperature difference, the HVAC controller **150** determines that a loss of refrigerant charge is possible. The HVAC controller **150** generates an alert signaling a possible loss of refrigerant charge. In various embodiments, the alert could be an auditory or visual alert. In other embodiments, the alert could include a message delivered to the communication device **155** or the monitoring device **156**.

For purposes of this patent application, the term computer-readable storage medium encompasses one or more tangible computer-readable storage media possessing structures. As an example and not by way of limitation, a computer-readable storage medium may include a semiconductor-based or other integrated circuit (IC) (such as, for example, a field-programmable gate array (FPGA) or an application-specific IC (ASIC)), a hard disk, an HDD, a hybrid hard drive (HHD), an optical disc, an optical disc drive (ODD), a magneto-optical disc, a magneto-optical drive, a floppy disk, a floppy disk drive (FDD), magnetic tape, a holographic storage medium, a solid-state drive (SSD), a RAM-drive, a SECURE DIGITAL card, a SECURE DIGITAL drive, a flash memory card, a flash memory drive, or any other suitable tangible computer-readable storage medium or a combination of two or more of these, where appropriate.

The term "substantially" is defined as largely but not necessarily wholly what is specified (and includes what is specified; e.g., substantially 90 degrees includes 90 degrees and substantially parallel includes parallel), as understood by a person of ordinary skill in the art. In any disclosed embodiment, the terms "substantially," "approximately," "generally," and "about" may be substituted with "within a percentage of" what is specified.

Depending on the embodiment, certain acts, events, or functions of any of the algorithms described herein can be performed in a different sequence, can be added, merged, or left out altogether (e.g., not all described acts or events are necessary for the practice of the algorithms). Moreover, in certain embodiments, acts or events can be performed concurrently. e.g., through multi-threaded processing, interrupt processing, or multiple processors or processor cores or on other parallel architectures, rather than sequentially. Although certain computer-implemented tasks are described as being performed by a particular entity, other embodiments are possible in which these tasks are performed by a different entity.

Conditional language used herein, such as, among others, "can," "might," "may," "e.g.," and the like, unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements and/or states. Thus, such conditional language is not generally intended to imply that features, elements and/or states are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without author input or prompting, whether these features, elements and/or states are included or are to be performed in any particular embodiment.

While the above detailed description has shown, described, and pointed out novel features as applied to various embodiments, it will be understood that various omissions, substitutions, and changes in the form and details of the devices or algorithms illustrated can be made without departing from the spirit of the disclosure. As will be recognized, the processes described herein can be embodied within a form that does not provide all of the features and benefits set forth herein, as some features can be used or practiced separately from others. The scope of protection is defined by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

What is claimed is:

1. A heating, ventilation, and air conditioning (HVAC) system comprising:
- an evaporator coil;
- a compressor fluidly coupled to the evaporator coil;
- a condenser coil fluidly coupled to the compressor, the condenser coil comprising:
  - at least one condenser circuit fluidly coupled between a discharge line and an exit manifold;
  - a sub-cool circuit fluidly coupled between the exit manifold and a liquid line;
  - a first temperature sensor disposed at an entrance to the sub-cool circuit;
  - a second temperature sensor disposed at an exit to the sub-cool circuit; and
- an HVAC controller operatively coupled to the first temperature sensor and the second temperature sensor, the HVAC controller configured to:
  - determine a first temperature difference across the sub-cool circuit;
  - add a refrigerant charge to the HVAC system;
  - determine a second temperature difference across the sub-cool circuit;
  - determine if the second temperature difference is greater than the first temperature difference;
  - responsive to a determination that the second temperature difference is greater than the first temperature difference, add additional refrigerant charge to the HVAC system; and
  - responsive to a determination that the second temperature difference is not greater than the first temperature difference, remove refrigerant charge from the HVAC system.

2. The HVAC system of claim **1**, wherein the HVAC controller is configured to generate an alert responsive to a change in a temperature difference.

3. The HVAC system of claim **1**, comprising a refrigerant reservoir fluidly coupled to the exit manifold.

4. The HVAC system of claim **3**, comprising a first valve disposed between the refrigerant reservoir and the exit manifold and a second valve disposed between the refrigerant reservoir and a suction line.

5. The HVAC system of claim **4**, wherein the first valve and the second valve are operatively coupled to the HVAC controller.

6. The HVAC system of claim **5**, wherein the HVAC controller is configured to at least one of add refrigerant to the HVAC system via the second valve and remove refrigerant from the HVAC system via the first valve.

7. A condenser coil comprising:
- at least one condenser circuit fluidly coupled between a discharge line and an exit manifold;
- a sub-cool circuit fluidly coupled between the exit manifold and a liquid line;
- a first temperature sensor disposed at an entrance to the sub-cool circuit;
- a second temperature sensor disposed at an exit to the sub-cool circuit;
- an HVAC controller operatively coupled to the first temperature sensor and the second temperature sensor, the HVAC controller configured to:
  - determine a first temperature difference across the sub-cool circuit;
  - add a refrigerant charge to the HVAC system;
  - determine a second temperature difference across the sub-cool circuit;
  - determine if the second temperature difference is greater than the first temperature difference;
  - responsive to a determination that the second temperature difference is greater than the first temperature difference, add additional refrigerant charge to the HVAC system; and
  - responsive to a determination that the second temperature difference is not greater than the first temperature difference, remove refrigerant charge from the HVAC system.

8. The condenser coil of claim **7**, where in the at least one condenser circuit comprises a plurality of condenser circuits.

9. The condenser coil of claim **7**, wherein the HVAC controller is configured to generate an alert responsive to a change in a temperature difference.

10. The condenser coil of claim **7**, comprising a refrigerant reservoir fluidly coupled to the exit manifold.

11. The condenser coil of claim **10**, comprising a first valve disposed between the refrigerant reservoir and the exit manifold and a second valve disposed between the refrigerant reservoir and a suction line.

12. The condenser coil of claim **11**, wherein the first valve and the second valve are operatively coupled to the HVAC controller.

13. The condenser coil of claim **12**, wherein the HVAC controller is configured to at least one of add refrigerant to the HVAC system via the second valve and remove refrigerant from the HVAC system via the first valve.

14. A method of charge management for an HVAC system, the method comprising:
- determining, with a first temperature sensor and a second temperature sensor, a first temperature difference across a sub-cool circuit;
- adding a refrigerant charge to the HVAC system;
- determining, with the first temperature sensor and the second temperature sensor, a second temperature difference across the sub-cool circuit;
- determining, with an HVAC controller, if the second temperature difference is greater than the first temperature difference;

responsive to a determination that the second temperature difference is greater than the first temperature difference, adding additional refrigerant charge to the HVAC system; and

responsive to a determination that the second temperature difference is not greater than the first temperature difference refrigerant charge causes the temperature difference to decrease, removing refrigerant charge from the HVAC system.

15. The method of claim **14**, wherein the HVAC controller directs the adding additional refrigerant to the HVAC system via a second solenoid valve electrically coupled to the HVAC controller and fluidly coupled between a refrigerant reservoir and a suction line.

16. The method of claim **15**, wherein the HVAC controller directs the removing refrigerant to the HVAC system via a first solenoid valve electrically coupled to the HVAC controller and fluidly coupled between the refrigerant reservoir and the exit manifold.

17. The method of claim **14**, comprising generating an alert responsive to a change in a temperature difference.

18. The method of claim **17**, further comprising:

determining, with the first temperature sensor and the second temperature sensor, a third temperature difference across the sub-cool circuit;

determining, with the HVAC controller, if the third temperature difference is greater than the second temperature difference;

responsive to a determination that the third temperature difference is greater than the second temperature difference, adding additional refrigerant charge to the HVAC system; and

responsive to a determination that the third temperature difference is not greater than the second temperature difference, determining with the HVAC controller, if the third temperature difference is between −1 and 0;

responsive to a determination that the third temperature difference is between −1 and 0, operating the HVAC system without adding or removing refrigerant charge; and

responsive to a determination that the third temperature difference is not between −1 and 0, removing refrigerant charge from the HVAC system.

19. The method of claim **17**, wherein the alert is transmitted to a communication device.

20. The method of claim **17**, wherein the alert is transmitted to a monitoring device.

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